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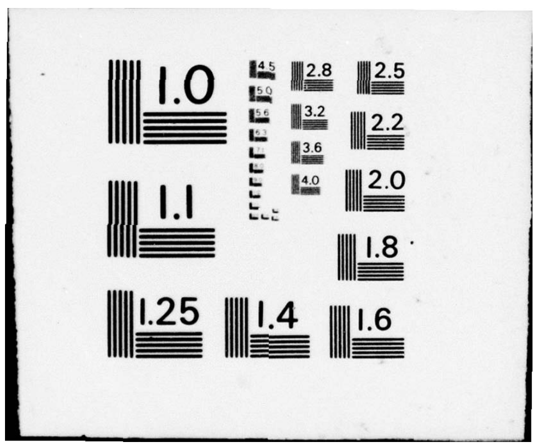
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OBSERVATIONS ALONG THE PIPELINE HAUL ROAD BETWEEN LIVENGOOD AND THE YUKON RIVER

R. Berg and N. Smith

October 1976

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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Periodic observations over a six-year period along the TAPS Road have been evaluated with respect to construction and slope stabilization techniques in ice-rich roadway cuts and embankment subgrades. Lateral drainage ditches of sufficient width to handle construction excavation equipment, along with near-vertical slope cuts with hand-cleared tops equal in width to one and one-half times the height of the cuts, significantly enhance natural processes of slope stabilization. Right-of-way clearing limited to the toe of embankment fill slopes minimizes subsidence of the roadway and its shoulder slopes. In extremely ice-rich soil cuts, the seeding of the slopes should not be attempted until late in the first thaw season for best results. Natural woody growth can be expected to have a substantial stabilizing

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effect after five or six thaw seasons but could be accomplished sooner by planting tree seedlings. Attempts to stabilize ice-rich cut slopes with applications of insulation are not very effective and seem to prolong the natural stabilization process.

PREFACE

This report was prepared by Dr. Richard L. Berg and North Smith, Research Civil Engineers of the Northern Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The studies were conducted under DA Project 4A762719AT42 Design, Construction and Operations Technology for Cold Regions, Technical Area 03, Facilities Technology, Work Unit 001, MESL Roads and Airfields in a Winter Environment and OCE Project Order No. Eng-CRREL-76-1, Consolidated Trans-Alaska Pipeline Research Program, Work Unit, Expedient and Permanent Roads and Airfields.

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Multiply	by	To Obtain
inch	25.4*	millimeter
foot	0.3048*	meter
mile	1.609344	kilometer

* Exact

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INTRODUCTION

In 1968 large oil resources were located in the Prudhoe Bay region of Alaska's North Slope. To move the oil to markets in the 48 contiguous states, a consortium of oil companies formed a company to construct a pipeline from Prudhoe Bay to the ice-free port of Valdez on the southern coast of Alaska. To facilitate construction of the pipeline, the companies proposed building a new road from near Livengood to Prudhoe Bay. The road would pass through areas where no permanent roads had been constructed previously (Fig. 1). The first approximately 56 miles (90.1 km) of the "haul road" were constructed from September 1969 through July 1970 between Livengood and the Yukon River. Road construction north of the Yukon River was delayed by several court injunctions against the proposed pipeline. In April 1974, the U.S. Congress authorized construction of the trans-Alaska oil pipeline and the remaining 370 miles (595.4 km) of haul road were completed during that summer. Although the immediate purpose of the entire haul road is to provide access for pipeline construction equipment and material, it will ultimately become part of the state highway system. The haul road was therefore constructed to the State of Alaska Department of Highways secondary road standards. The portion of haul road ("TAPS Road") between Livengood and the Yukon River was transferred to the state in 1972.

The main purpose of this report is to present a photographic record of the performance of several ice-rich cuts which were encountered on the TAPS Road. At three locations we made transverse level observations to monitor the performance of a cut slope and two embankment sections. The roadway alignment, borrow areas and distance markers corresponding to locations of photographic and level sites discussed here, except for mile 4.5 (7.2 km) and mile 16.3 (26.2 km), are shown in Figures 2-6. Distances were measured from the south end of the road. We photographed many more sites than those shown in this report; however, the sites discussed here are representative of the behavior of most problem cuts on this road. Our previous discussions of 1970 and 1971 observations on cuts at miles 19.6 (31.6 km) and 20.25 (32.6) are contained in Smith and Berg (1973). Pufahl et al. (1974) documented observations on recent highway cuts in Canada and Alaska, including some of those described in this report.

PHOTOGRAPHIC DOCUMENTATION AND OBSERVATIONS

Kovacs (1970) was the first CRREL investigator to travel the haul road. His primary purpose was to study the ice bridge across the Yukon River. He reported to us that several cuts had been made through

ice-rich soils. For the purpose of this report, the first trip we made was on 23 April 1970. We made eleven additional trips at the times shown in Table 1 to document the performance of selected cut slopes. Approval for the initial trips had to be obtained from Trans-Alaska Pipeline System (now Alyeska Pipeline Services Company) personnel. These initial investigations were conducted in conjunction with expedient road studies at the CRREL Alaskan Field Station in Fairbanks. Vehicles of various types, including sedans, 4-wheel drive crew-cab pickups and 4-wheel drive utility vehicles, have been used. The traffic surface and alignment of the haul road are generally much better than those of the older portions of the Elliot Highway south of Livengood.

We chose for photographic documentation those sites which were expected to develop the most serious maintenance problems when thawing commenced.

Figure 7 illustrates the idealized behavior of an ice-rich cut. At the time of construction, trees are cleared back from the face of the slope for a distance approximately equal to one and one-half times the height of the cut. Clearing is accomplished by hand to minimize damage to the organic mat (Fig. 7a). The cut is nearly vertical, typically with 0.25:1 backslopes, and wide ditches are used so that earth moving equipment can clean them if necessary. The roadway is undercut by about 5 ft (1.5 m) before the granular embankment is placed.

During the first summer after road construction the slope degrades rapidly, is extremely unstable due to release of excess water and is quite unsightly. Seeding is accomplished late in the thaw season by hydraulic methods. The amount of grass that survives is influenced by the ice content of the soil, the exposure of the slope and other conditions. Frequently a large portion of the seeded grasses is lost by rotting because the seeds are covered by cold, wet soil. Some of the new-grown grass may be smothered by sloughing cold, wet soil or the grass may slide down the slope into the parallel drainage ditch because the new root systems have not penetrated deeply into the underlying soil (Fig. 7b). Depending on the magnitude of thawing and the ice content of the thawing soil, it may be necessary to clean the ditches.

In subsequent years the rate of degradation of the backslopes continually decreases. The organic mat extends farther downslope as the ice-rich soils thaw and the slope continues to recede. Its insulating effect retards further melting and sloughing. After five or six thaw seasons the slope reaches a relatively stable condition. The artificially seeded vegetation develops significantly and the natural grasses and woody plants reestablish themselves. The surface cover provided by this vegetation also retards further erosion of the permafrost table (Fig. 7c).

In several of the following photographic sequences, the ice-rich cuts have performed similarly to the idealized case described above. Many of the cuts now appear to be relatively stable; however, Pufahl et al. (1974) state:

> Many slope angles are very steep (35° to 40°) and the present conditions probably do not represent long-term stable slope angles for most of the colluvial silt encountered along the route. It is conceivable, therefore, that adverse pore water conditions developing in the backslope could initiate instability, re-expose ice wedges, and re-initiate the cycle of melting, sloughing, draining, and stabilizing.

Nearly all of the ice-rich cuts were approximately in the first twenty-four miles (38.6 km) of the haul road, which lies south of Hess Creek (Figs. 2-4). Several of the cuts were too shallow to present major maintenance problems, but five relatively deep cuts were made between about mile 19.6 (31.6 km) and Hess Creek, at about mile 23.6 (38.0 km). As the following photographs show, ice volumes in the cuts at 19.6 mi (31.6 km), 19.9 mi (32.0 km), 20.25 mi (32.6 km), 22.9 mi (36.8 km), and 23.2 mi (37.3 km) were very impressive in April 1970 when viewed prior to substantial thawing. The first of the deep cuts was made at mile 19.6 (31.6 km) and was excavated at a 1:1 backslope. When other similar high-ice-content soils were encountered, the use of nearly vertical backslopes was instituted. It was reasoned that less of the ice-rich soil would be exposed, and also that the vegetative cover would remain intact and slowly slump over to cover and insulate the receding surface. Wide drainage ditches were made in these cuts to facilitate removal, if necessary, of thawed soil and any debris with earth-moving equipment. Where the road crossed high-ice content soils it was undercut and backfilled with about 5 ft (1.5 m) of blasted and/or crushed rock to reduce anticipated differential settlements.

We observed significant changes in the roadway and backslopes on successive visits in 1970 and 1971 which indicated that considerable maintenance was required. The engineers were aware of these possible problems at the time of construction, but they estimated that maintenance costs would be less than design and construction costs if attempts were made to eliminate the problems. Now, six years after construction, many of the backslopes appear to have reached an equilibrium condition.

As suggested by Smith and Berg (1973) the roadbeds in these areas do not appear to be stablizing as rapidly as the backslopes. During the 1970 and 1971 summers, differential settlements of 6 in. (152 mm) or more occurred where the road crossed ice-rich soils or masses of ice. Differential settlement problems in the center portion of the roadway are not as severe now, due to a thicker embankment and increased

maintenance by patrol graders while the pipeline is being constructed. The major distress is now occurring in the shoulders and ditches of the roadway. In some locations sizeable "holes" have resulted from subsidence of the shoulder and ditches. Some of these shoulder failures have advanced into the roadway causing a narrower travel surface. Figure 8, a photograph taken at mile 23.2 Lf, is typical of this type of problem. Since the roadway surface is gravel, these types of problems can be repaired by simply hauling in additional granular fill.

After their encounters with cuts in ice-rich soils between Livengood and the Yukon River, Alyeska engineers took measures to minimize the number of cuts between the Yukon River and Prudhoe Bay. The topography in the northern portions of the road also required fewer cuts. McPhail et al. (1975) describe maintenance measures on the "Happy Valley Cut" in the foothills north of the Brooks Range. This cut was necessary to provide an acceptable grade for ascending from the Sagavanirktok River flood plain to an upland terrace about 200 ft (61.0 m) higher in elevation.

Mile 4.5 (7.2 km) Right

This cut slope faces southwest and the top of the slope is 8-10 ft (2.4-3.0 m) above the roadway surface. The upper portion of a massive ice mass can be observed 3-4 ft (0.9-1.2 m) below the top of the slope in Figures 9 and 10. These two photographs, taken on 26 June 1970 show that the mineral soil overlying the ice is relatively dry. Figures 11 and 12 show the grass growth from June till August 1970. Figures 13-15 show the slope on 27 May 1971. A small amount of litter from the previous years' growth of grasses is visible and the organic mat is hanging over the thawed soil; however, it has torn in some places. Figures 16 and 17, taken nearly two years later, show the remnants of a substantial growth of grass. The slope does not have a "neat" appearance, however. Figures 18 and 19 show the slope on 27 September 1974. A few small trees are visible at this time and a substantial growth of grass has occurred during the summer. Figures 20 and 21 show the slope on 14 September 1975. The trees had grown considerably since the previous year. Due to their shading effect, thus permitting less thaw and removal of subsurface moisture, the trees and grasses have assisted in making this a relatively stable slope.

Mile 9.85 (15.85 km) Right

There are actually two slopes involved here, both facing in a southwesterly direction. Figures 22 and 23 illustrate a large mass of ice visible in a shallow cut on 23 April 1970. Figure 24 shows the slope on 11 August 1970. A good growth of grasses had started where the slope was not rapidly degrading. A gravel berm had been placed near the toe of the slope to allow drainage of excess water and to partially

restrain the mineral soil as it fell from the receding ice. On 28 May 1971 the berm was easily observed (Fig. 25 and 26). Most of the slope appeared relatively stable but a small part continued to degrade rapidly (Fig. 26). Figure 27, taken on 27 September 1974, shows the same area as Figure 24 and represents a nearly stable condition on the shallow slope.

The second slope at this site developed stability problems during the second thaw season. It can be seen at the extreme left in Figure 25. It is much higher but the ice-rich soil was not exposed during construction. The photographs taken on 17 August 1971, Figures 28 and 29, show the massive movement and the disruption of the relatively heavy grass cover caused by subsurface thawing. The slope looked quite stable in September 1974 when last photographed. The grass cover had rehealed and some small trees had started to grow (Fig. 30).

Mile 19.6 (31.6 km) Left

The performance of this slope during the 1970 and 1971 summers is discussed by Smith and Berg (1973). This was the first major ice-rich cut encountered along the road and was the only one made at a nominal 1.1 backslope (Fig. 31). On the remaining deep high ice content cuts, essentially vertical backslopes were made. Figures 32 and 33 show that by 26 June 1970 considerable degradation of the slope had occurred. The ditch was nearly full of wet, muddy soil. Material in the ditch was not sufficiently stable to support a small rock tossed from the roadway shoulder. Between June and August 1970 the ditch was cleaned and a revetment installed (Fig. 34, 35 and 36). The slope had also been hydroseeded but little grass had been established due to rapid degradation of the slope. By May 1971 material in the ditch had dried sufficiently to support a man's weight and the backslope appeared relatively dry (Fig. 37 and 38). Little additional degradation of the slope occurred during the 1971 summer and material in the ditch contained several desiccation cracks on 17 August 1971, as shown in Figures 39 and 40. On 23 June 1972, the slope was in a condition similar to that observed previously (Fig. 41 and 42). This slope was completely snow-covered in April 1973 and was not photographed in 1974. In September 1975 the slope looked quite stable (Fig. 43 and 44). Grasses and willows had established themselves on most of the slope. In the three summers between June 1972 and September 1975 the apparent stability of this slope improved dramatically.

Mile 19.9 (32.0 km) Left

This slope faces the northeast. Figure 45 shows a large mass of ice in the cut on 23 April 1970. This slope degraded rapidly and by September 1970 a shot rock revetment had been installed in the ditch

(Fig. 46). Figure 47 illustrates the organic mat hanging over the receding slope on 28 May 1971. On 17 August 1971 portions of the slope looked fairly stable (Fig. 48), while on other parts of the slope the organic mat had torn and vegetation was sparse (Fig. 49). The slope was in a similar condition in June 1972 (Fig. 50). During the summer of 1973 a major portion of this backslope was re-excavated to expose the ice-rich permafrost. An experiment was initiated to determine the effects of spraying foamed-in-place insulation on such backslopes as an alternative method for achieving slope stability. Polyurethane insulation was sprayed onto the newly exposed slope and the cleared area above the slope. Figure 51 is a photograph of the slope on 27 September 1974 and Figure 52 is a close-up of the insulation. Figures 53 and 54 show the slope on 14 September 1975. Lush grass is evident above and below the insulating layer and at a few breaks in the insulation. The surface of the insulation had degraded noticeably, but the slope did not appear to be melting and receding. It will be very interesting to observe the behavior of this slope for the next few years. Quite possibly this slope would have healed to the extent of those previously discussed if the insulation had not been applied.

Mile 20.25 (32.6 km) Left

This slope faces nearly due east. The original cut face extended approximately 30 ft (9.1 m) above the road surface at its highest part. The performance of this slope from 23 April 1970 through 17 August 1971 was discussed by Smith and Berg (1973). Figures 55-60 illustrate the performance of the slope during that period. Most of the large ice masses were encountered between approximately 5 and 15 ft (1.5 and 4.6 m) below the top of the cut. Initially the slope receded rapidly, but material deposited at the base of the cut as the ice melted was considerably drier than that from mile 19.9 (32.0 km) (Figs. 56-58). Figures 61 and 62 taken on 23 June 1972 and Figure 63 taken on 20 April 1973 show that recession of the slope had slowed considerably. Since both photographs were taken early in the thawing season, the extent of vegetative growth was difficult to ascertain although most of the slope appeared to be covered by grass. On 27 September 1974 the slope was covered with tall grasses, (Fig. 64). Small birch trees were evident near the base of the ditch at that time also. By 14 September 1975 grasses and trees covered the slope extensively. Many of the trees appeared to be 10 ft (3.0 m) tall or taller (Fig. 65 and 66). As the root systems increase in size and number, stability of the slope is enhanced by the additional demand for soil water and the "anchoring" effect of the roots.

On two occasions elevations were taken up this slope starting at the outside edge of the drainage ditch. The resulting slope profiles

are shown in Figure 67. There has been quite a large volume of material eroded from the slope. Most of it, however, has been water which, when excavated in the frozen state, requires the expenditure of huge amounts of energy. This points out a consideration for choosing the best method of excavating cuts in such terrain. Often it is best to cut nearly vertical slopes and allow for natural stabilization. The difficulties one faces with this method of stabilization are erosion, high maintenance costs and stream pollution.

Mile 22.9 (36.8 km) Left and Right

In this cut the left slope faces nearly east; naturally, the right slope faces nearly west.

On the left side of the road, the top of the cut is about 10 ft (3.0 m) above the road surface. Massive ice was observed on 23 April 1970 (Fig. 68) extending from about 5 ft (1.5 m) below the top of the cut down to the drainage ditch. This large mass of ice was exposed over most of the length of the cut, probably 100 ft (30 m) or more. Because a relatively small volume of mineral soil had overlain the massive ice, much of the ice was still visible on 26 June 1970 (Fig. 69). Figures 70-74 illustrate that a portion of the slope continued to degrade through the 1972 summer. However, by 27 September 1974 most of the slope was covered by a dense cover of grasses (Fig. 75). A few small trees were also observed at that time. This site was not photographed in September 1975; however, future observations will determine whether the recession of a portion of the slope continues. The lack of tree growth on the slope is undoubtedly due to the absence of birch and willow trees in the area. As seen in the photographs, spruce is the predominant tree type, and it is not a rapid self-propagating species.

The right side cut at this site also contained a massive ice inclusion (Fig. 76). Behavior of this side was similar to that observed on the left except that the mineral soil deposited in the ditch as the ice melted appeared to be more moist (Figs. 77-80). The cut was mostly snow-covered in 1973 (Fig. 81) but on 27 September 1974 it appeared mostly stable (Fig. 82). Grass on this side seemed to be less dense and shorter than on the left side, making the slope appear less stable.

This cut is almost certainly the one described by Jackman (1974). His schematic figures are similar to our Figure 7 and illustrate processes which were observed by us and others, e.g. Lotspeich (1971), at other cuts on the road.

Our photographic documentation, however, shows no evidence of woody plants until the fourth thaw season, rather than the second as stated by Jackman.

Mile 23.2 (37.3 km) Left

This slope also faces almost due east. Figure 83 illustrates the massive ice which was encountered in part of this cut on 23 April 1970. Vegetation on top of this slope had been damaged more significantly by equipment than on other slopes, so to reduce vertical thaw penetration a fibrous insulating material was placed (Fig. 84). The fibrous material was the same material used for mulch in the hydroseeding mixture for the slopes. By 28 May 1971 a coarse rock berm had been placed near the base of the slope to aid in stabilizing it (Fig. 85). At the end of the 1971 summer, grass had become established on a major portion of the slope, but other segments continued to degrade (Fig. 86). Little change in the slope was observed on 23 June 1972 (Fig. 87). Grasses were better established by 27 September 1974 (Fig. 88), and by 14 September 1975 a few birch and willow trees were growing (Fig. 89). The trees on this slope were not as numerous or as large as those observed on some of the other slopes.

Mile 33.1 (53.3 km) Right and Mile 33.3 (53.6 km) Right

These two slopes are actually portions of a nearly continuous side-hill cut. Both slopes face nearly due west. Figure 90 shows both of these slopes. The dark line in the center is the melt zone runoff from the slope at Mile 33.1 (53.3 km) and the high slope with the large bench is at mile 33.3 (53.6 km). The truck near the center of the photograph serves as a scale for estimating the height of the cut at mile 33.3 (53.6 km). Most of the material at mile 33.3 (53.6 km) is bedrock; however, the cut at mile 33.1 (53.3 km) was much shallower and contained a large volume of ice which became exposed during the 1970 summer (Fig. 91 and 92). Figures 93 and 94 show both cuts in September 1970; the ice-rich portion at mile 33.1 (53.3 km) had receded considerably during the summer months. Figures 95 and 96 show the slope at mile 33.1 (53.3 km) on 28 May 1971 and Figure 97 shows the slope of mile 33.3 (53.6 km) on the same date. By 17 August 1971 the slope at mile 33.1 (53.3 km) had receded beyond the clearing limit above the cut and several trees had fallen onto the slope (Fig. 98). The height of the actively receding face can be compared with the height of the man near the center of the photo. By 23 June 1972 the major portion of the face was covered by fallen trees and the overhanging organic mat (Fig. 99). The rate of recession had undoubtedly slowed considerably by that time. Figures 100 and 101 show the condition of the slopes in May 1973. By 27 September 1974 grasses covered most of the slope at mile 33.1 (53.3 km) (Fig. 102) and receding appeared to have stopped. The slope at mile 33.1 (53.3 km) was not photographed in September 1975, but Figure 103 shows part of the slope at mile 33.3 (53.6 km) at that time. Some grasses and small trees had reestablished where the original organic mat was intact or where mineral soils were of adequate thickness to support them.

The slope at mile 33.1 (53.3 km) was the last major ice-rich cut on the original Livengood to Yukon River portion of the haul road. During the summer of 1974 approximately the last 7 miles of the haul road were relocated to facilitate construction of pump station 6 on the pipeline and to meet with the Yukon River bridge. The original alignment provided access to the winter ice bridge crossing and air-cushion/barge ferrying point in the summer. Ice-rich cuts were exposed on the relocated segment and their performance will be monitored during subsequent observations of the cuts described here.

CROSS-SECTION OBSERVATIONS

On the second trip up the haul road, i.e. in June 1970, we decided to establish sites to observe the long-term performance of the haul road and the cleared right-of-way adjacent to it. The primary objective of these sites was to document the performance of approximately 5 ft (1.5 m) of fill placed on the cleared surface where cuts were not required.

We established two cross-section sites, the first at mile 16.3 (26.2 km) and the second at mile 50.7 (81.6 km). Figure 104 is a general view of the road and surroundings near mile 16.3 (26.2 km). The road runs in a north-northwesterly direction at this location. The right-of-way was cleared for a width of about 170 ft (51.8 m), with the roadway centerline being approximately 110 ft (33.5 m) from the left clearing limit. The site is at station 869+70 where a temporary bench mark used during road construction was available for these observations. The design crown width of the roadway was 28 ft (8.5 m).

Figures 105 and 106 look left and right, respectively, at the cross section site on 27 June 1970. As seen in the photographs, trees were removed and the organic mat was stripped on each side of the road. The stripped material was replaced after constructing the embankment, and during the 1970 summer the areas were seeded.

Dates that cross-section observations were made are shown in Table II. Figure 107 illustrates changes in the cross section from August 1970 through September 1975. The roadway was not at finished grade at this location in late June 1970, so the initial observations in Figure 107 are those for 11 August 1970. Figure 108 shows subsidence since observations were initiated for the four numbered points in Figure 107. The roadway centerline has subsided the least, 0.65 ft (0.2 m), whereas the toe of the slope at point 2 has subsided nearly 3.0 ft (0.9 m). The roadway appears to be settling relatively uniformly and its width has not changed significantly since 1970 (Fig. 107). Figure 109 is a photograph of this site on 30 May 1975. Although the photo was taken early in the summer, remnants of the previous summer's growth of grass are visible. No young trees were observed growing in the disturbed area.

Figures 110 and 111 illustrate the conditions at the second cross-section site on 27 June 1970. This site is at station 2710+00 at about mile 50.7 (81.6 km). The finished grade elevation was 1177.5 ft (358.8 m) and the width of the roadway surface was about 28 ft (8.5 m). The section is located in a relatively flat area with very little vertical grade on the road which runs in a northwesterly direction. At this site the trees and vegetation had been disturbed for a width of only about 20 ft (6.1 m) beyond the toe of the slope on each side of the road. Figure 112 illustrates changes in cross-section levels for this section from 27 June 1970 through September 1975. The roadway centerline has subsided about 1.25 ft (0.38 m) since it was constructed. Reasons for the settlement can be inferred from exploratory borings for the pipeline in that vicinity (Fig. 113). The boring logs were taken from Alyeska (1971) and the locations were within 500 ft (150 m) of the cross-section site. Occasional to considerable amounts of visible ice were encountered in the top 3 to 6 ft (1 to 2 m) of overburden. This would easily account for the recorded settlements.

The site is slightly beyond the junction of the relocated segment of the road to pipeline pump station 6 on the Yukon River. Observations will continue on the site if access can be maintained.

CONCLUSIONS

Recommendations by Smith and Berg (1973) after observing these cuts for two summers remain valid. The guidelines are restated below with some slight modifications from those presented in 1973. The modifications have been made because of a longer study period and the recent growth of woody plants on some of the slopes.

Guidelines for making cuts through ice-rich soils are:

1. Cut nearly vertical backslopes on the cuts.

2. Provide a wide ditch at the base of the cut to allow removal of material if necessary and to allow deposition of some overlying material during the stabilization process. A wide ditch will also permit a porous revetment to be made to enhance drainage and stabilization of the slope.

3. Clear trees and brush from the top of the slope for a distance about equal to one and one-half times the height of the slope. Stumps should be cut as close to the soil surface as possible; i.e. stumps should be less than 1 ft (0.3 m) high. Although it was not done on any of these slopes, nailing a course wire mesh to the stumps would provide additional tensile strength to the organic mat and reduce the amount of

tearing of it, especially on higher backslopes. As melting and subsidence occur during the stabilization process, it might be necessary to remove additional trees from the top of the slope. This cutting, as well as the initial cutting, should be accomplished with hand tools. Heavy construction equipment should not be used outside the lateral limits of the excavation area.

4. Vegetative seeding should be attempted only on relatively stable portions of the slopes at selected times. If the slope is exposed in the early spring, near the end of the first thaw season the lower portion of the slope should be heavily seeded with annual and perennial grasses and fertilized. This will establish a relatively firm and stable toe of slope down to the drainage ditch before heavy melting occurs the following thaw season. Following this procedure for two or three years should establish the grasses in successive stages up the slope to meet with the subsiding organic mat from the top of the cut. During the second and third summer, seedlings of willow and birch trees could also be placed. These trees have grown very rapidly during the 1974 and 1975 (5th and 6th) summers. They apparently were not planted but grew from root-stock or seeds deposited by natural means such as wind, rain, animals and birds.

Table I. Locations and dates of photographic documentations.

Mile location and side of road (heading north)	4/23/70	6/26/70	8/11/70	9/70	5/27/71	8/17/71	6/23/72	4/20/73	5/73	9/27/74	5/30/75	9/14/75
4.5 Rt		X	X		X			X		X		X
9.85 Rt	X		X		X	X				X		
16.3		X									X	
19.6 Lf	X	X	X		X	X	X					X
19.9 Lf	X			X	X	X	X			X		X
20.25 Lf	X	X	X		X	X	X	X		X		X
22.9 Lf	X	X	X	X	X		X	X		X		
22.9 Rt	X		X		X	X		X		X		
23.2 Lf	X		X		X	X	X			X		X
33.1 Rt		X	X	X	X	X	X		X	X		
33.3 Rt		X		X	X				X			X
50.7		X										

Table II. Locations and dates of level observations.

Mile location and type of Observation	6/27/70	8/11/70	9/01/70	8/11/71	6/23/72	4/20/73	5/23/73	9/27/74	9/14/75
16.3 Embankment Cross section	X	X	X	X	X		X	X	X
20.25 Left cut Slope						X		X	
50.7 Embankment Cross section	X	X	X	X	X		X	X	X

Literature Cited

Alyeska Pipeline Service Company (1971). Project description of the Trans-Alaska Pipeline System. Appendix-Road Drawings-Vol. 3, Appendices-Volumes 18 and 20.

Jackman, A.H. (1974) Highway cut stabilization in areas of permafrost and ground ice. Proceedings, Association of American Geographers, vol. 6.

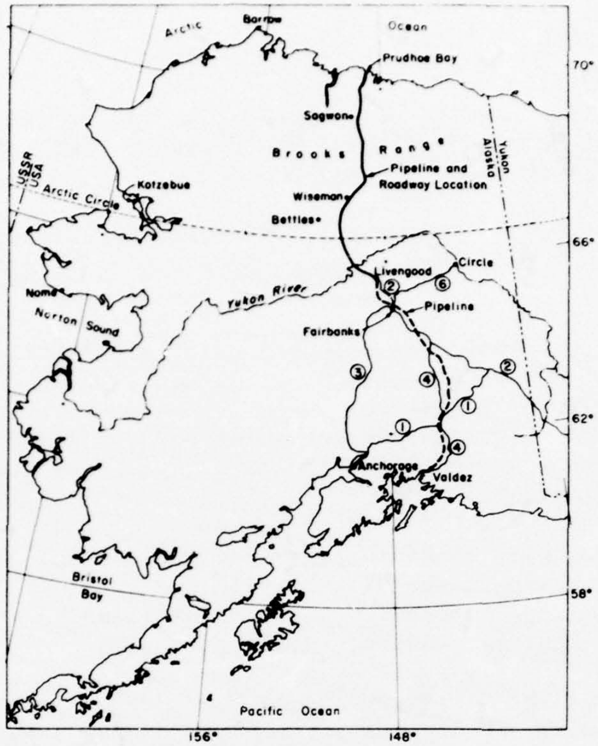
Kovacs, Austin (1970). An informal note on the TAPS ROAD and ICE BRIDGE. USACRREL Technical Note, May 1970 (unpublished).

Lotspeich, F.B. (1971). Environmental guidelines for road construction in Alaska. Environmental Protection Agency, Alaska Water Laboratory, College, Alaska.

McPhail, J.F., W.B. McMullen, and A.W. Murfitt(1975) Design and construction of roads on muskeg in arctic and subarctic regions. 16th Annual Muskeg Research Conference, National Research Council of Canada, Montreal, Quebec, October 7, 1975.

Pufahl, D.E., N.R. Morgenstern, and W.D. Roggensack (1974) Observations on recent highway cuts in permafrost. Department of Civil Engineering University of Alberta, Edmonton, Alberta, March 1974.

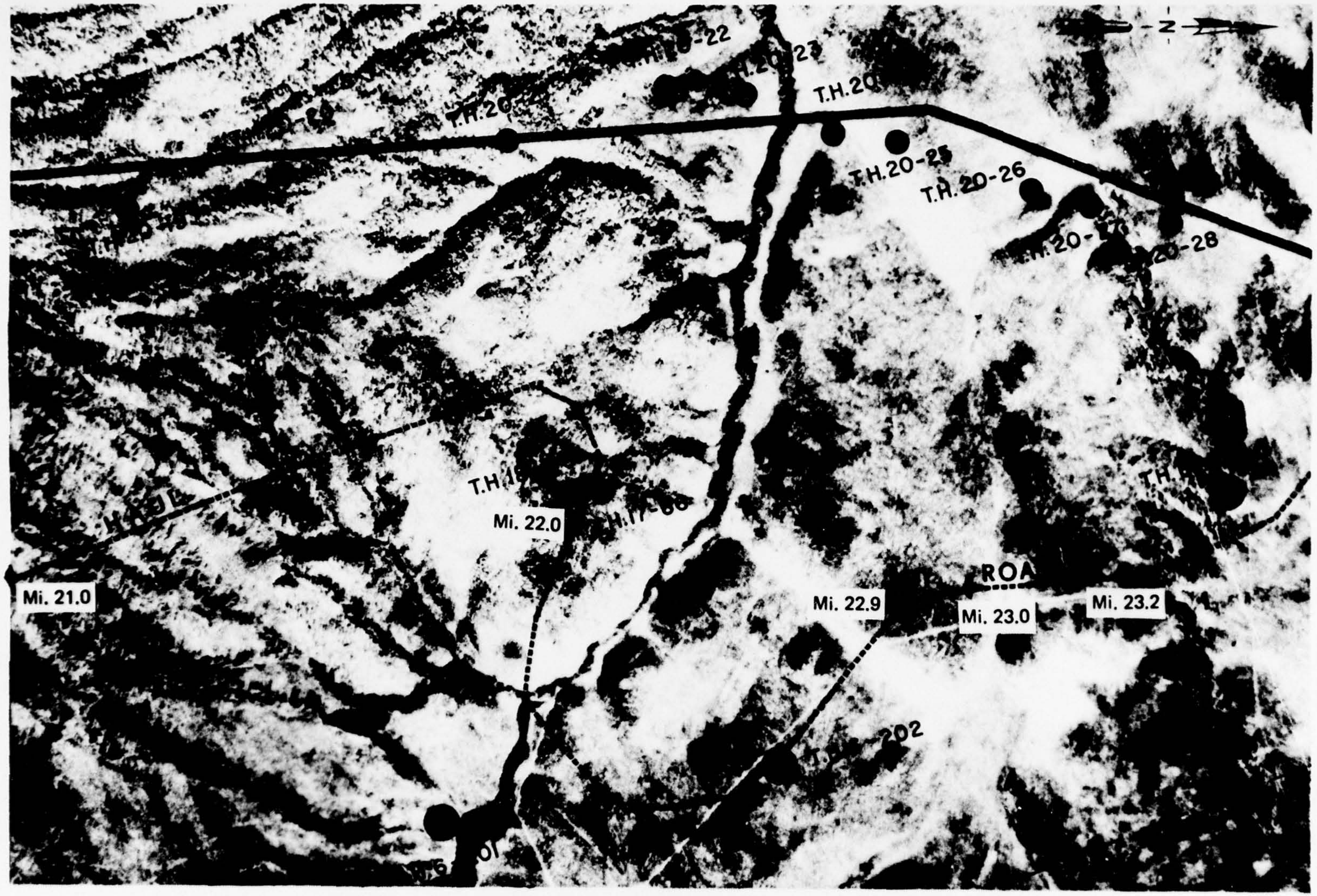
Smith, North and Richard Berg (1973) Encountering massive ground ice during road construction in central Alaska. The North American Contribution to the Second International Conference on Permafrost, National Academy of Sciences, 1973.



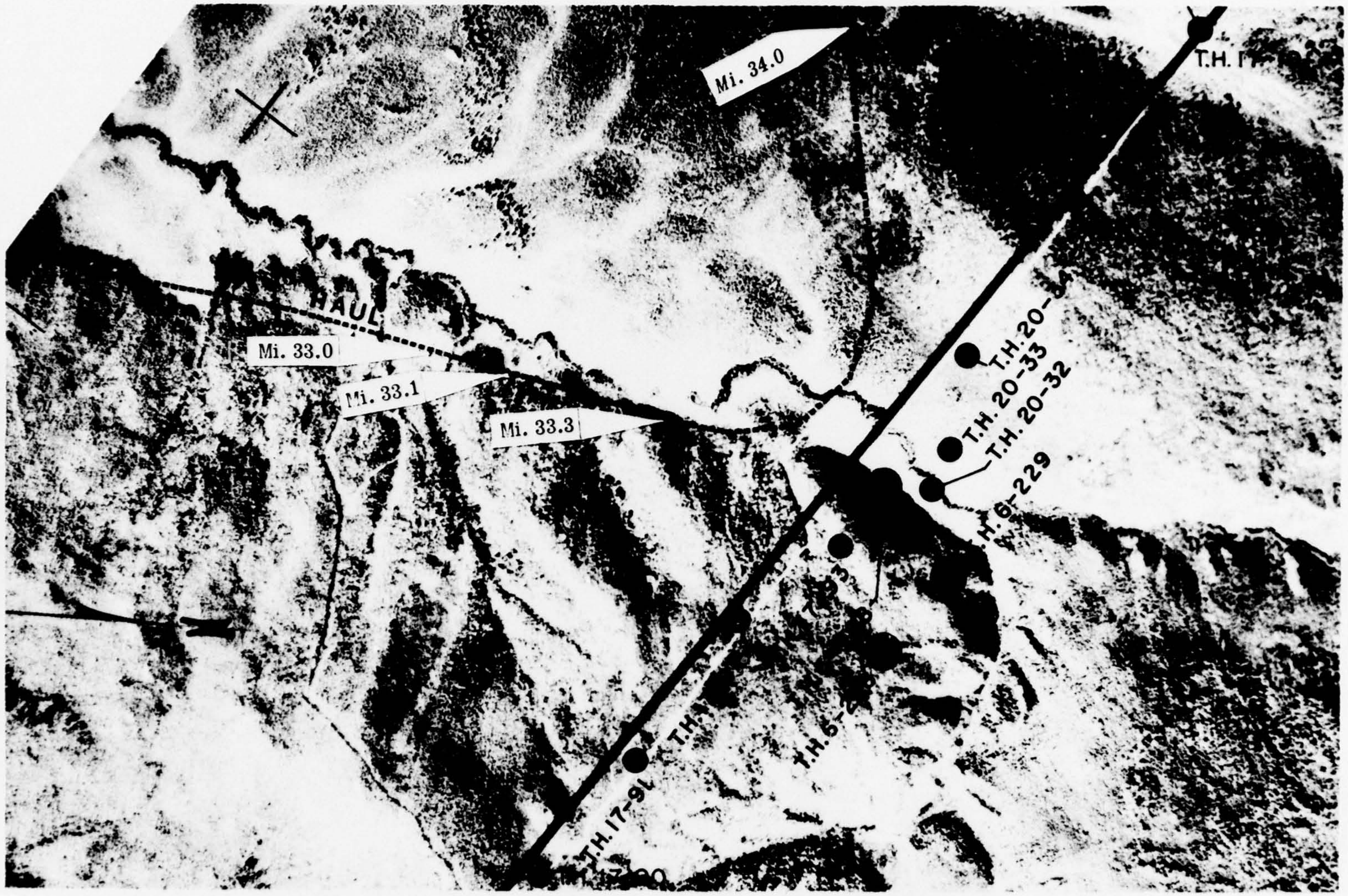
1. Map of Alaska showing pipeline and haul road routes.

2. Miles 9-11 (approx.).

3. Miles 19-21 (approx.).

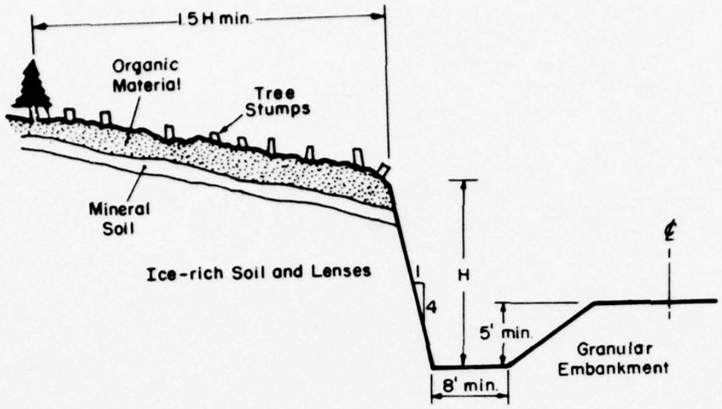


4. Miles 21-24 (approx.).

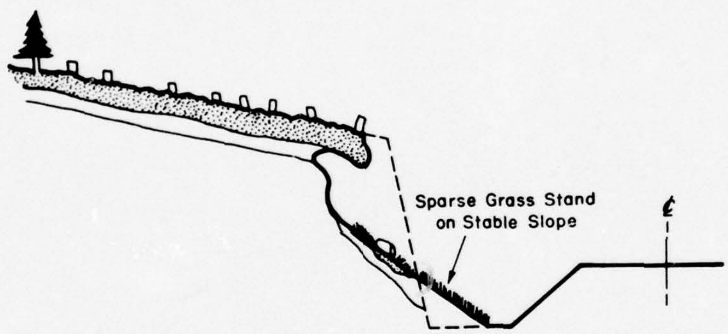


5. Miles 32-34 (approx.).

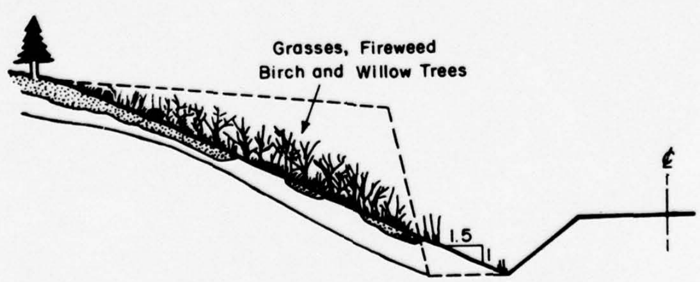
6. Miles 50-52 (approx.).



a. Initial frozen cut profile.



b. End of first thaw season. Slope is mostly unstable and very unsightly; ditch will require cleaning if massive ice is present.



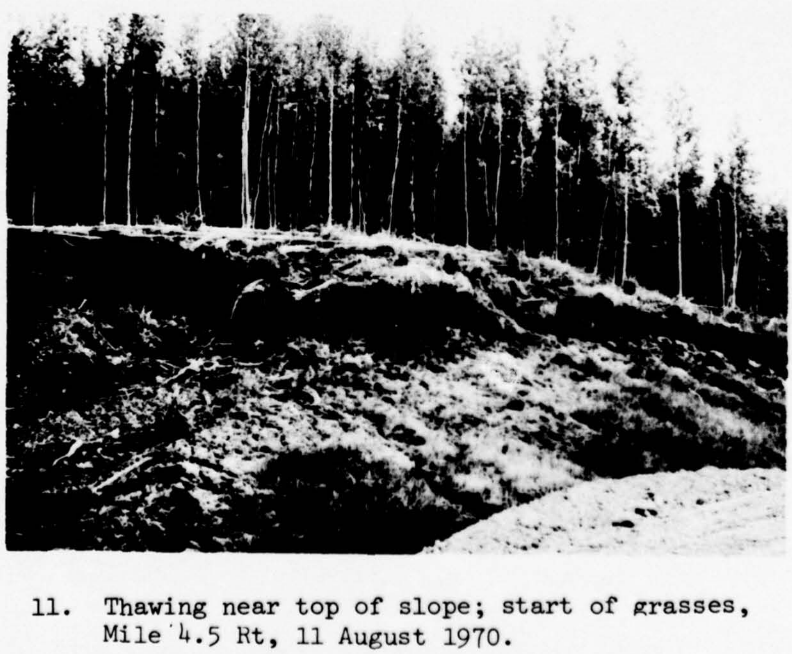
c. End of fifth or sixth thaw season. Slope stabilizes with reduced thaw and vegetation established. Free water from minimal thawing is used by plants whose root systems develop new organic material.

7. Idealized development of stability in ice-rich cut.

8. Thaw subsidence in ditch at Mile 23.2 Lf.

9. Thawing backslope, Mile 4.5 Rt, 26 June 1970.

10. Organic mat overhanging part of thawing backslope, 26 June 1970.



11. Thawing near top of slope; start of grasses, Mile 4.5 Rt, 11 August 1970.

12. Most active thawing, Mile 4.5 Rt, 11 August 1970.

13. Southern end of receding and seeded backslope, Mile 4.5 Rt, 27 May 1971.

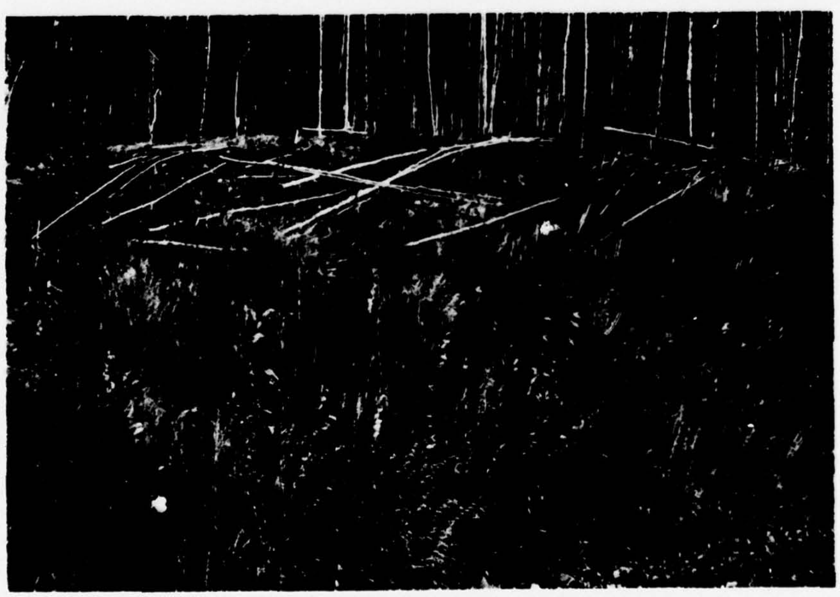
14. Center of receding and seeded backslope, Mile 4.5 Rt, 27 May 1971.

15. Close-up of most unstable portion of backslope, Mile 4.5 Rt, 27 May 1971.

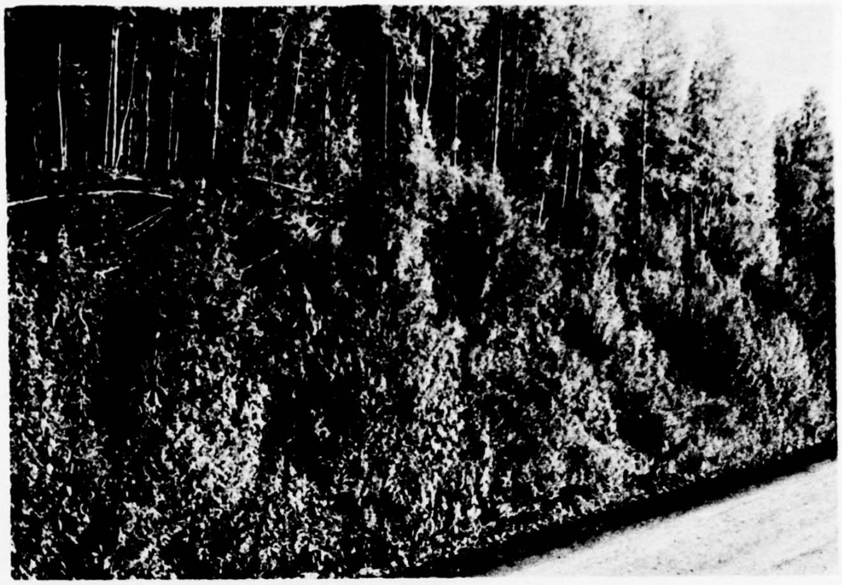
16. Southern end of backslope, Mile 4.5 Rt, 20 April 1973.

17. Center of partially snow-covered slope, Mile 4.5 Rt, 20 April 1973.

18. Southern end of backslope, Mile 4.5 Rt, 27 September 1974.



19. Center portion of backslope, Mile 4.5 Rt, 27 September 1974.

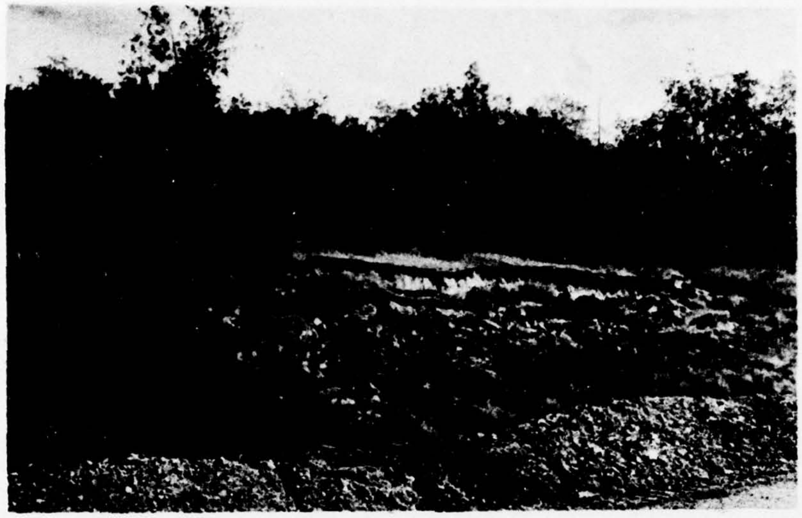


20. Southern end of backslope, Mile 4.5 Rt, 14 September 1975.

21. Center portion of backslope, Mile 4.5 Rt, 14 September 1975.

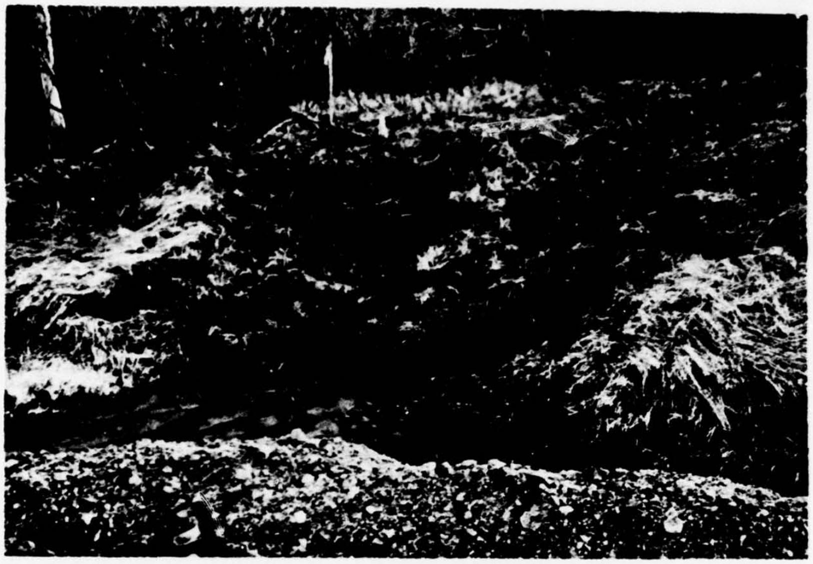
22. Massive ice in shallow cut, Mile 9.85 Rt, 23 April 1970.

23. Close-up of massive ice in shallow cut, Mile 9.85 Rt, 23 April 1970.



24. Thawing shallow backslope with grass and gravel berm, Mile 9.85 Rt, 11 Aug 1970.

25. Relatively stabilized shallow cut, Mile 9.85 Rt, 28 May 1971.

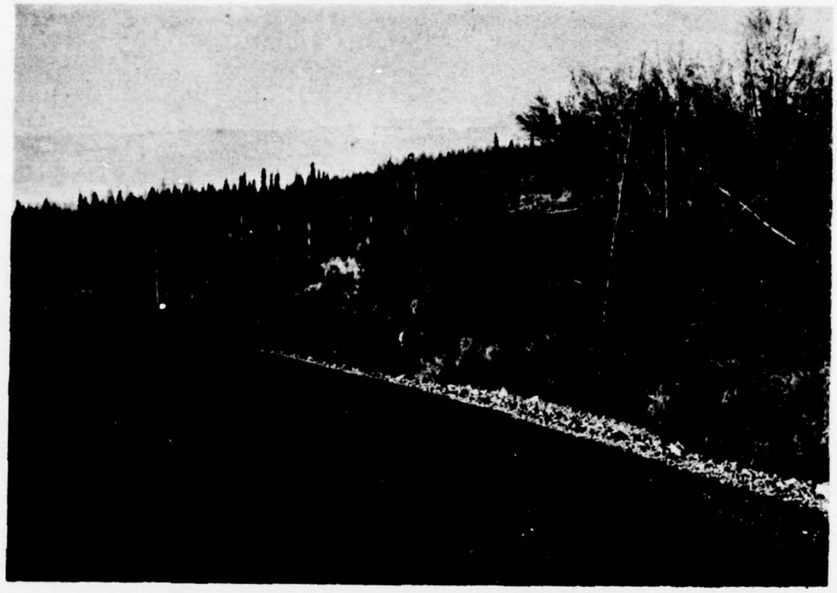


26. Receding portion of shallow cut, Mile 9.85 Rt,
28 May 1971.

27. Stabilized shallow backslope, Mile 9.85 Rt,
27 Sept 1974.

28. Most unstable portion of deep cut, Mile 9.85 Rt, 17 August 1971.

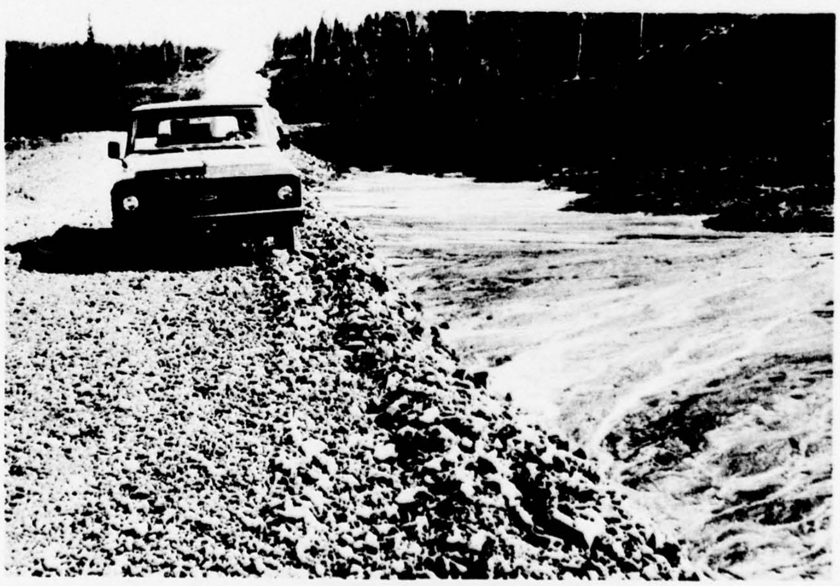
29. Overall view of deep cut, Mile 9.85 Rt, 17 August 1971.



30. Overall view of stabilized deep cut, Mile 9.85 Rt, 27 September 1974.

31. Frozen, partially snow-covered 1:1 backslope, Mile 19.6 Lf, 23 April 1970.

32. Thawing backslope, Mile 19.6 Lf, 26 June 1970.



33. Backslope erosion into parallel ditch,
Mile 19.6 Lf, 26 June 1970.

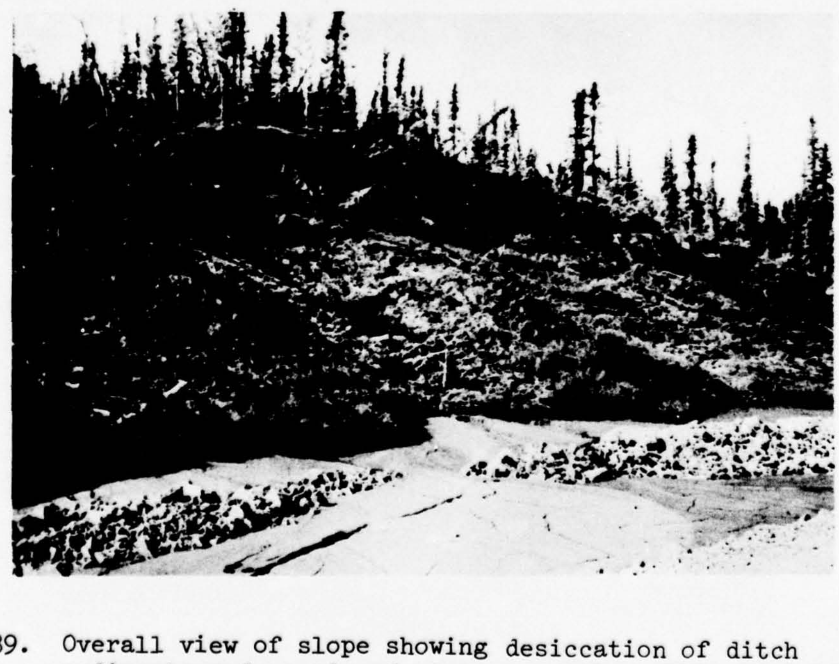
34. Seeded backslope and broken rock revetment, Mile 19.6 Lf, 11 August 1970.

35. Thawing slope receding into limit of clearing, Mile 19.6 Lf, 11 August 1970.

36. Mud flow on thawing backslope, Mile 19.6 Lf, 11 August 1970.

37. Receding backslope and stabilized ditch sediments, Mile 19.6 Lf, 23 May 1971.

38. Close-up of overhanging vegetative mat, Mile 19.6 Lf, 28 May 1971.



39. Overall view of slope showing desiccation of ditch sediments and continued slope recession, Mile 19.6 Lf, 17 August 1971.

40. Close-up of grasses in ditch and continued thawing of backslope, Mile 19.6 Lf, 17 August 1971.

41. Overall view of slope showing toppling spruce trees, Mile 19.6 Lf, 23 June 1972.

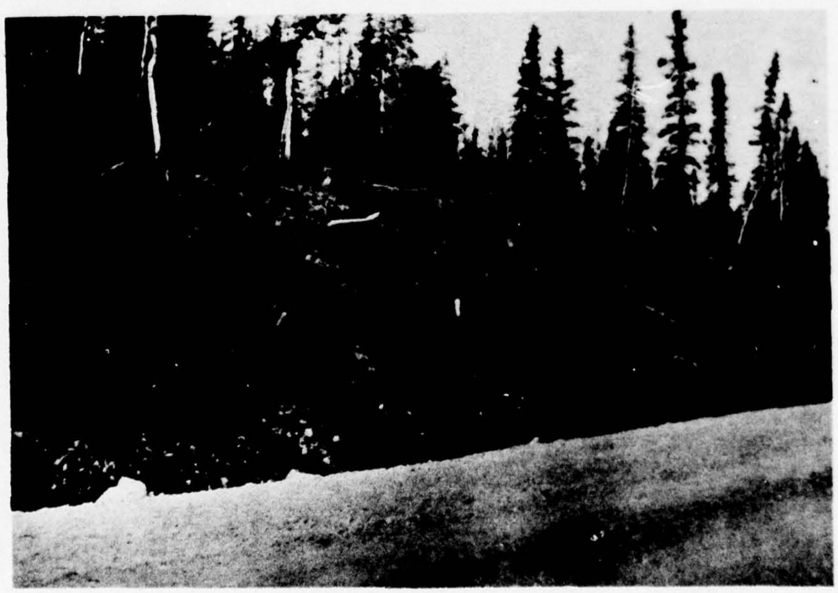
42. Grasses growing higher up the slope, Mile 19.6 Lf, 23 June 1972.

43. Sectional view of slope covered with small trees, Mile 19.6 Lf, 14 September 1975.

44. Center portion of slope showing birch trees, Mile 19.6 Lf, 14 September 1975.

45. Massive ice in frozen backslope, Mile 19.9 Lf, 23 April 1970.

46. Seeded backslope, overhanging mat and broken rock revetment, Mile 19.9 Lf, September 1970.



47. Sloughing slope overtopping broken rock revetment, Mile 19.9 Lf, 28 May 1971.

48. Part of backslope appearing fairly stable, Mile 19.9 Lf, 17 August 1971.

49. Overall view of backslope, Mile 19.9 Lf, 17 August 1971.

50. Overall view of backslope, Mile 19.9 Lf, 23 June 1972.

51. Insulation covering backslope, Mile 19.9 Lf, 27 September 1974.

52. Close-up of insulation, Mile 19.9 Lf, 27 September 1974.

53. Insulated backslope, Mile 19.9 Lf, 14 September 1975.

54. Insulated and uninsulated portions of backslope, Mile 19.9 Lf, 14 September 1975.

55. Frozen nearly-vertical backslope with large ice masses, Mile 20.25 Lf, 23 April 1970.

56. Ice face with overhanging mat and clearing atop backslope, Mile 20.25 Lf, 26 June 1970.

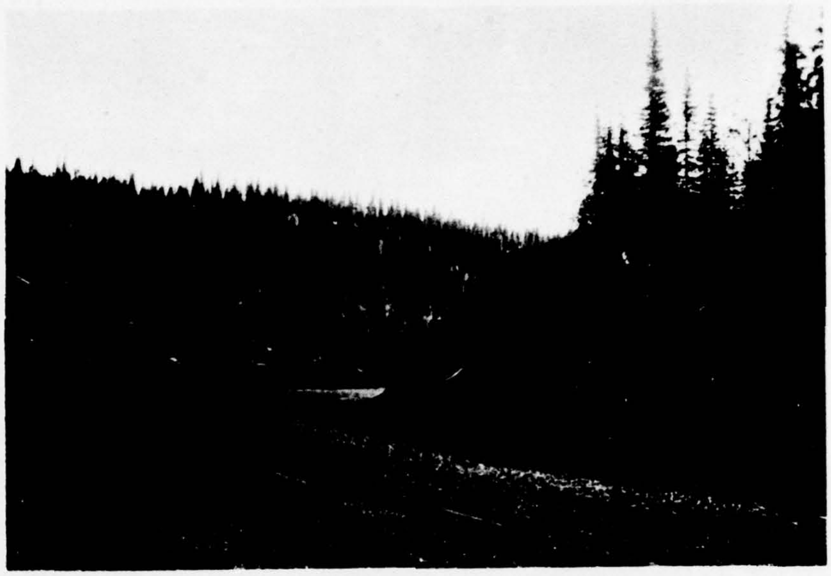
57. Ice face with overhanging mat and hydroseeded lower portion of slope, Mile 20.25 Lf, 11 August 1970.

58. Overall view of slope, Mile 20.25 Lf, 28 May 1971.

59. Overall view of slope, Mile 20.25 Lf, 17 August 1971.

60. Untidy appearance and continued thawing of backslope, Mile 20.25 Lf, 17 August 1971.

61. Overall view of slope, Mile 20.25, 23 June 1972.



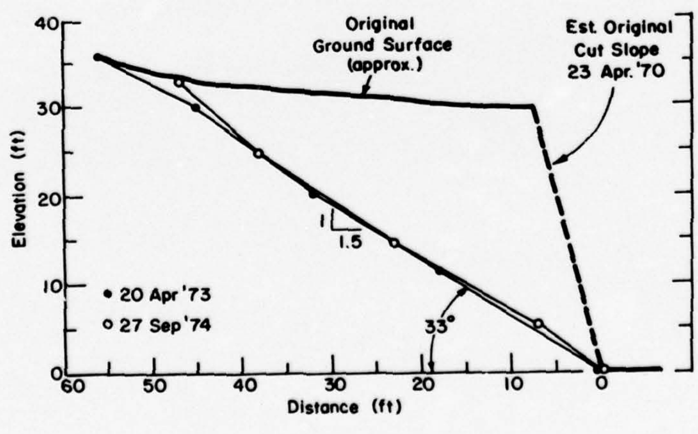
62. Stable north end of left slope and steep right slope, Mile 20.25, 23 June 1972.

63. Snow covered slope, Mile 20.25 Lf, 20 April 1973.

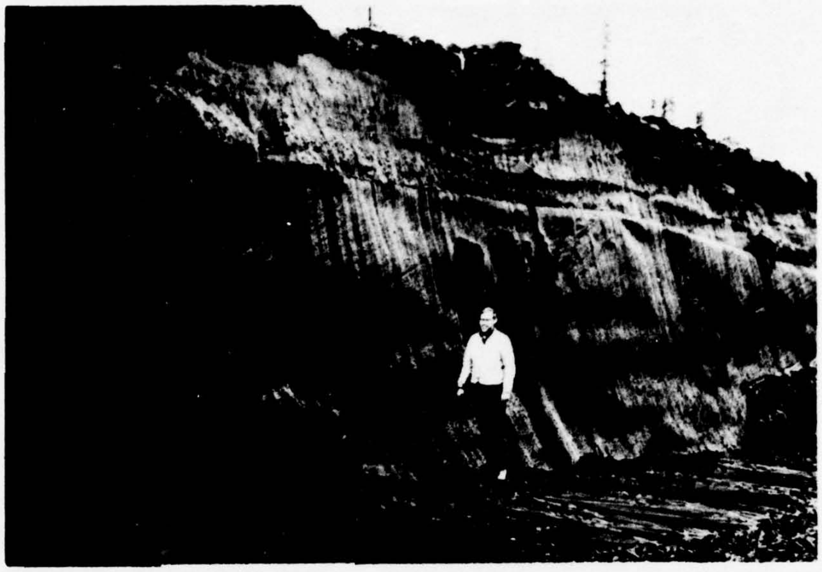
64. Small trees on slope, Mile 20.25 Rt, 27 September 1974.

65. Slope covered with small trees, Mile 20.25 Rt, 14 September 1975.

66. Tall trees near ditch line on portion of backslope, Mile 20.25 Lf, 14 September 1975.



67. Slope profile measurements, Mile 20.25 Lf.



68. Massive ice in frozen backslope, Mile 22.9 Lf, 23 April 1970.

69. Massive ice still visible, Mile 22.9 Lf, 26 June 1970.

70. Started grasses on portion of slope, Mile 22.9 Lf, 11 August 1970.

71. Grass not started on portion of backslope, Mile 22.9 Lf, September 1970.

72. Unstable portion of backslope, Mile 22.9 Lf, 28 May 1971.

73. Continued instability of backslope, Mile 22.9 Lf, 23 June 1972.

74. Snow-covered slope, Mile 22.9 Lf, 20 April 1973.

75. Grass-covered slope, Mile 22.9 Lf, 27 September 1974.

76. Massive ice in frozen backslope, Mile 22.9 Rt, 23 April 1970.

77. Parts of backslope stabilized and other sections receding, Mile 22.9 Rt, 11 August 1970.

78. Center portion of slope, Mile 22.9 Rt, 28 May 1971.

79. Northern portion of slope, Mile 22.9 Rt, 23 June 1972.

80. Center portion of slope, Mile 22.9 Rt, 17 August 1971.

81. Backslope with snow cover, Mile 22.9 Rt, 21 April 1973.

82. Backslope with small amount of grass, Mile 22.9 Rt, 27 September 1974.

83. Massive ice in frozen backslope, Mile 23.2 Lf, 23 April 1970.

84. Center portion of slope showing fibrous insulation on cleared top of backslope, Mile 23.2 Lf, 11 August 1970.

85. Gravel berm near base of backslope, Mile 23.2 Lf, 28 May 1971.

86. View of slope showing grass growth and continued slumping, Mile 23.2 Lf, 17 August 1971.

87. Overall view of backslope, Mile 23.2 Lf, 23 June 1972.

88. Close-up of vegetation and relatively dry mass of soil not supporting grass, Mile 23.2 Lf, 27 September 1974.

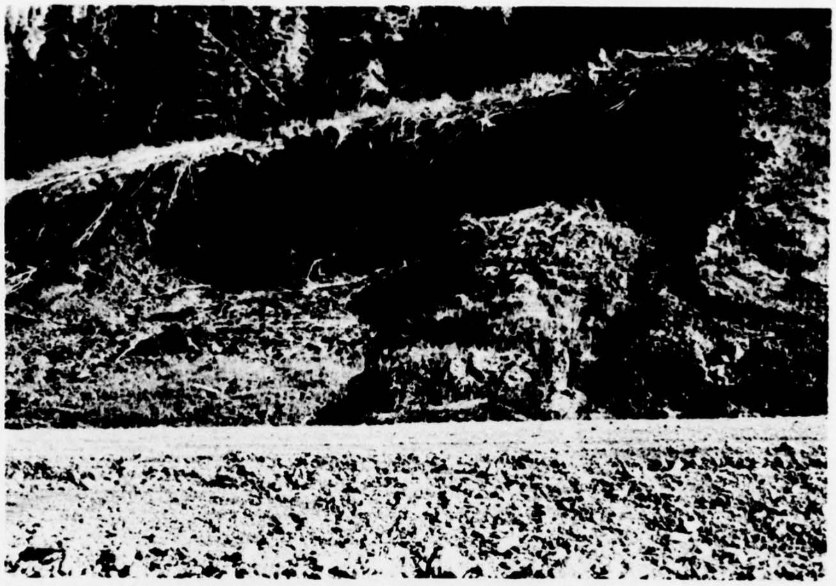
89. Grasses and small trees on backslope, Mile 23.2 Lf, 14 September 1975.

90. Overall view of backslopes, Mile 33.1 Rt in foreground and Mile 33.3 Rt in background, 26 June 1970.

91. Close-up of start of sloughing, Mile 33.1 Rt, 26 June 1970.

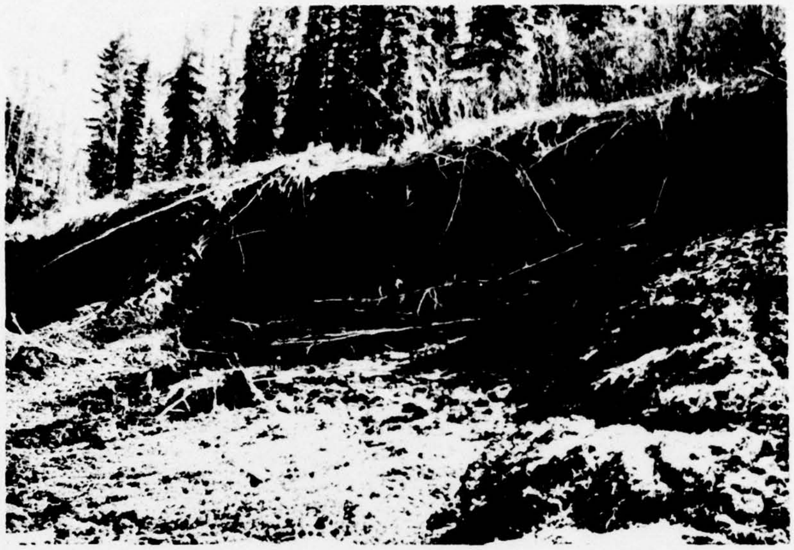
92. Ice-rich backslope, Mile 33.1 Rt, 11 August 1970.

93. Overall view of backslopes, Mile 33.1 and 33.3 Rt, September 1970.



94. Receding slope, Mile 33.1 Rt, September 1970.

95. Northern end of slope, Mile 33.1 Rt, 28 May 1971.



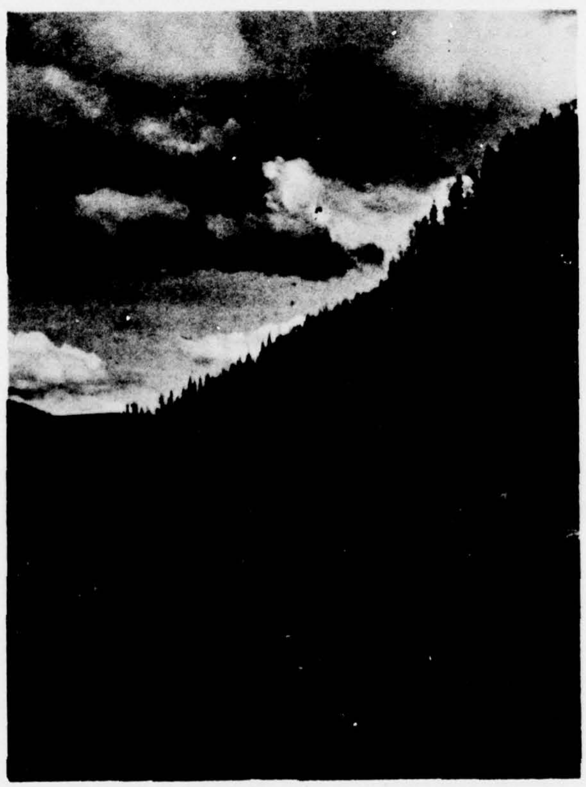
96. Center portion of slope with mat overhanging ice face, Mile 33.1 Rt, 28 May 1971.

97. Benched slope, Mile 33.3 Rt, 28 May 1971.

98. Receding slope with open ice face, Mile 33.1 Rt, 17 August 1971.

99. Fallen trees and overhanging mat, Mile 33.1 Rt, 23 June 1972.

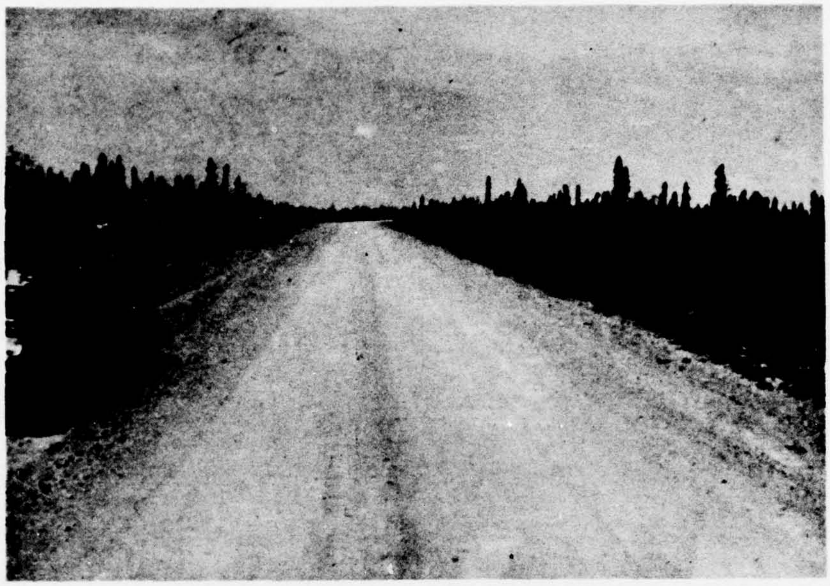
100. Grass and debris on backslope, Mile 33.1 Rt, May 1973.



101. Overall view of backslope, Mile 33.3 Rt, May 1973.

102. Relatively stable backslope, Mile 33.1 Rt, 27 September 1974.

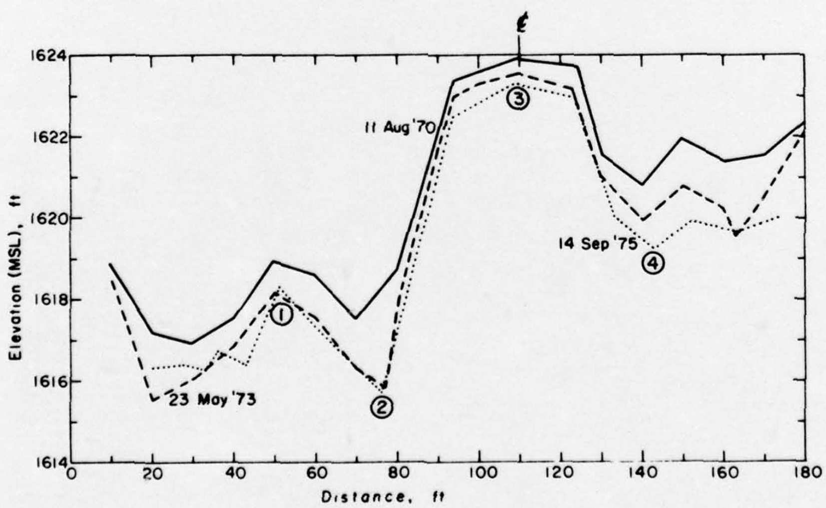
103. Overall view of backslope, Mile 33.3 Rt, 14 September 1975.



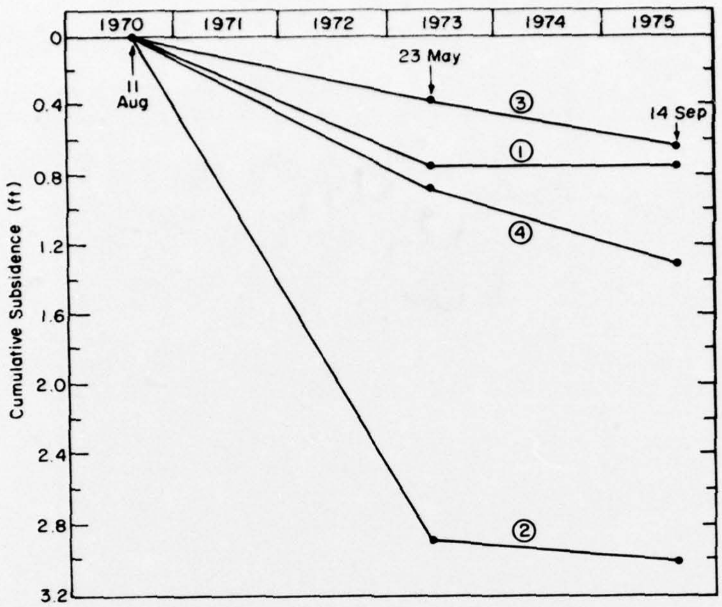
104. General view north on centerline of road, Mile 16.3, 27 June 1970.

105. Left embankment slope, Mile 16.3, 27 June 1970.

106. Right embankment of slope, Mile 16.3, 27 June 1970.

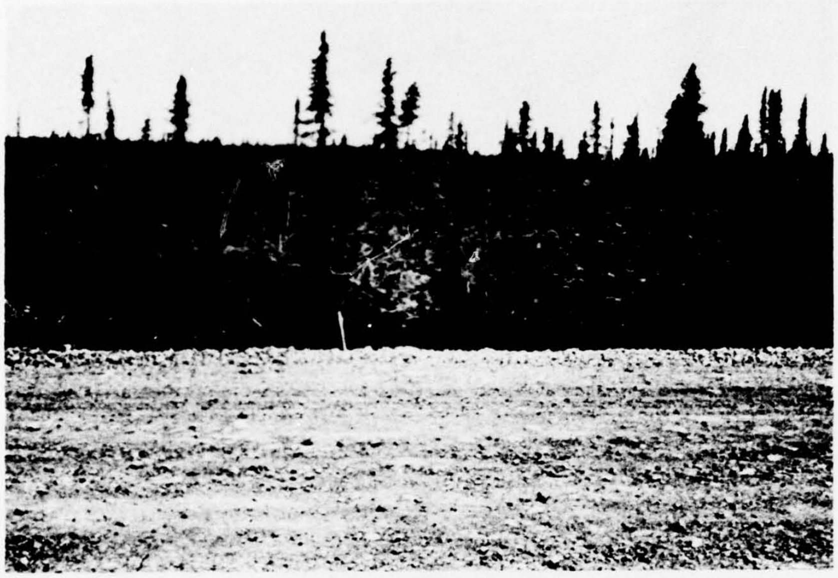


107. Profile changes in cross-section at Mile 16.3, August 1970 - September 1975.



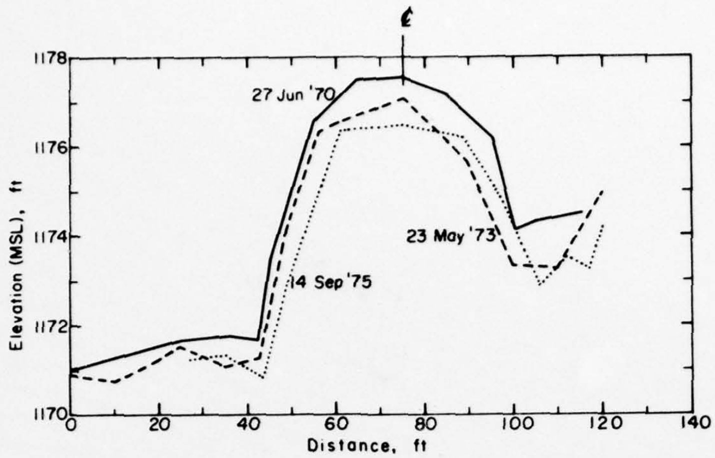
108. Subsidence versus time at selected points on cross-section at Mile 16.3

109. Centerline looking north, Mile 16.3, 30 May 1975.

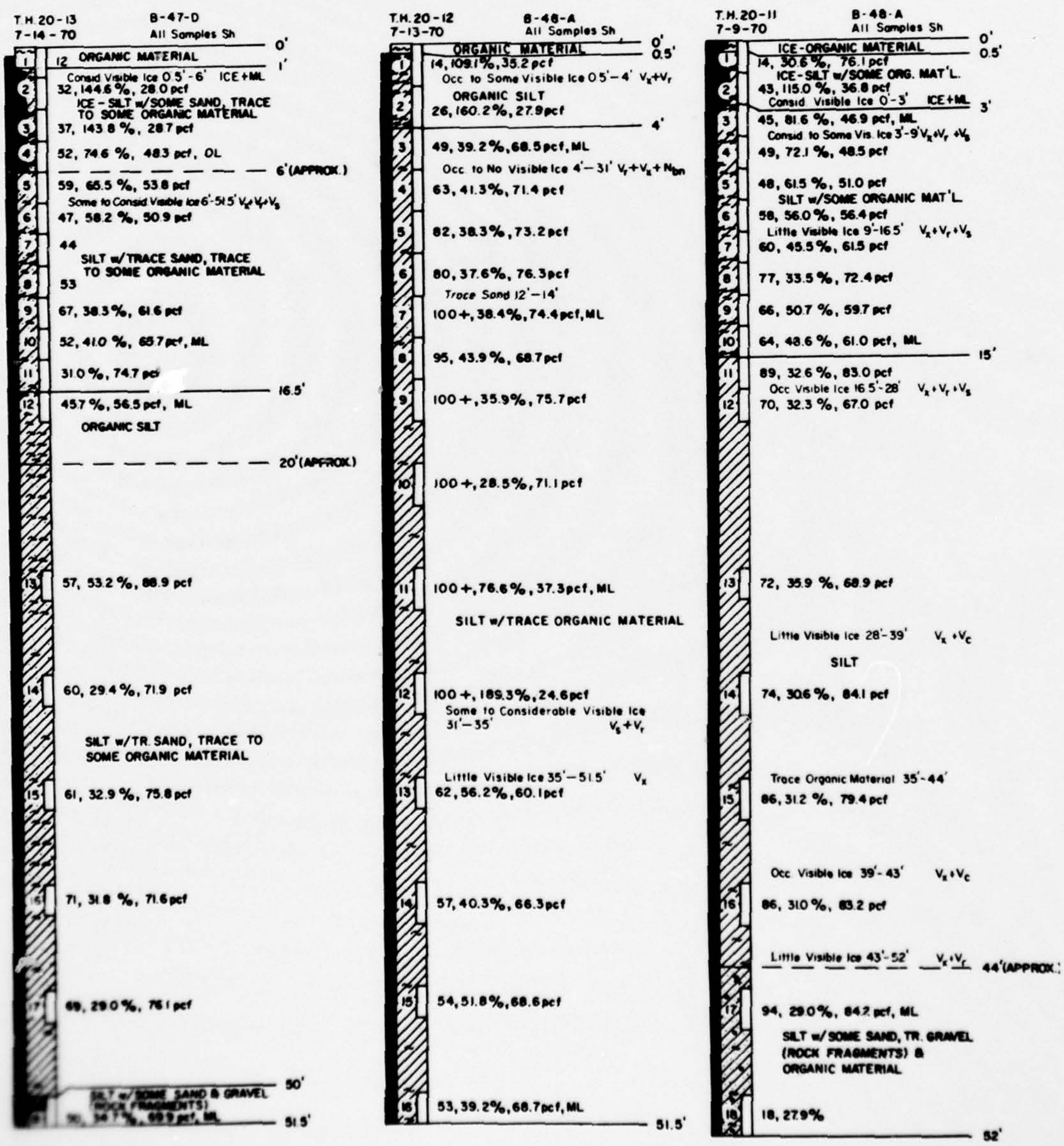


110. Left side of road, Mile 50.7, 27 June 1970.

111. Right side of road, Mile 50.7, 27 June 1970.



112. Profile changes in cross-section at Mile 50.7, June 1970 - September 1975.



113. Soil boring logs in vicinity of Mile 50.7 (81.6 km) of TAPS Road.